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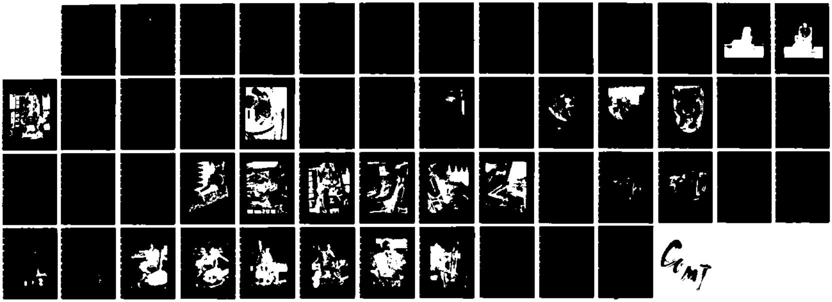

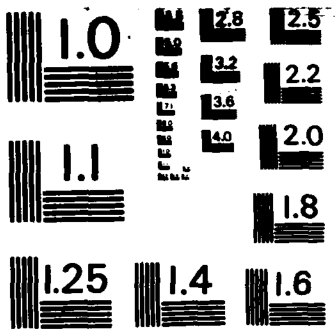

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PERFORMANCE EVALUATION OF THE HI-SPEED EJECTION LIMB PROTECTION SYSTEMS (HELPS)

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The HELPS performance evaluation consisted of a series of tests to evaluate deployment, cinch-up and restraint effectiveness. Test facilities used to evaluate HELPS included the NADC Ejection Tower, the Dayton T. Brown Windblast Facility and an F-14 Aircraft which was made available at the Naval Air Test Center, Patuxent River. The following pages describe the results of these evaluations.

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INTRODUCTION

The purpose of this program was to test and evaluate the performance of the Hi-Speed Ejection Limb Protection System (HELPS). This evaluation investigated three critical functions of the HELPS operation; deployment, cinch-up and restraint.

The program was sponsored by the Naval Air Systems Command, code AIR 340-B under an exploratory development phase study whose objective is to develop and evaluate the feasibility and practicality of various approaches to satisfy new requirements or improve current deficiencies. HELPS was developed under Contract No. N62269-77-C-0251 by Stencel Aero Engineering Corporation. The system under evaluation was delivered to the Naval Air Development Center in February 1981.

SUMMARY

An extensive performance evaluation was conducted on HELPS. The functions evaluated were deployment, cinch-up and restraint. Test facilities used in this evaluation included the NADC Ejection Tower, the Dayton T. Brown Windblast Facility and an F-14 Aircraft made available at the Naval Air Test Center, Patuxent River. The following pages describe the test results.

CONCLUSIONS

The method used to deploy the HELPS restraint straps and netting is unacceptable. After complete deployment and cinch-up, HELPS provides sufficient restraint to prevent limb flail.

RECOMMENDATIONS

An alternate method should be developed for deployment of a HELPS type restraint system.

SYSTEM DESCRIPTION AND EJECTION SEQUENCE

Reference 1 describes the background of the HELPS development program. This report updates that work and describes the latest system operation.

The HELPS prototype is shown in figure 1 in the stowed position in the MPES seat. As can be seen the system is completely seat mounted, primarily in the back and bottom cushions. The aircrewman is not required to don or connect anything. Figure 2 shows the system actuated and the HELPS deployed. Tension has been applied to capture and restrain the arms and legs.

As figure 2 illustrates, the inflatable bladders are used to deploy the HELPS. It includes 3500 pound Kevlar straps and netting which accomplish the actual restraint. The bladders may be inflated by gas generators of the type used in inflatable automotive impact systems or by high pressure stored gas.

The sequence of operation during an actual ejection would be as follows:

The HELPS is initiated by actuation of the ejection control. Within 150 milliseconds, four bladders are inflated, two over the aircrewman's knees and two aside his upper torso. This is accomplished before the seat begins to travel up the rails. Simultaneously, the power retraction inertia reel pulls the upper torso to the seat back. The shoulder deployment bladders inflate slightly ahead of the leg deployment bladders, positioning the shoulder restraint strap forward of and higher than the occupant's shoulders. The force applied by the inflating leg deployment bladders causes the shoulder restraint straps to strip off the shoulder deployment bladders. The straps are positioned down across his shoulders, and with the aid of the arm restraint net captures and sweeps the arms inboard. The initial seat motion causes the portion of the straps positioned over the knee to strip off the leg deployment bladders and become tensioned across his upper legs, down the inside of each knee and across his calves (figure 3). The arm restraint netting, attached to the strap network is tensioned around each arm, enveloping and restraining the elbows. It should be emphasized that because the strap deployment motion is over and around the shoulders and the upper arms, the arms are swept inboard toward the center of the seat. This motion was selected because the position of the arms and hands cannot be predicted during sequenced crew ejections. However, the location of the shoulders after powered haulback is known.

Further travel of the seat initiates a webbing "ripper" mechanism which generates a constant force to achieve leg retraction and to ensure that an adequate, but noninjurious, tension force is imparted to the straps. When the "ripper" separates, detaching the cockpit portion of the restraint straps, a strap snubber ensures that the tension force is maintained and prevents the straps from loosening.

As the seat leaves the aircraft and enters the windstream, the bladders deflate and either trail into or are torn loose by the windstream. The strap and netting retain the limbs - the legs against the seat side panel extensions, and the arms in toward the center of the seat and pinned to his body. The netting prevents the elbows and arms from egressing rearward into the windstream.

The restraint is maintained up to the point of seat/man separation when the restraint straps are released by the normal action of inertia reel strap cutter and lap belt release. The limb restraint harness assembly remains with the seat after seam/man separation to preclude interference with survival kit deployment and subsequent survival actions.

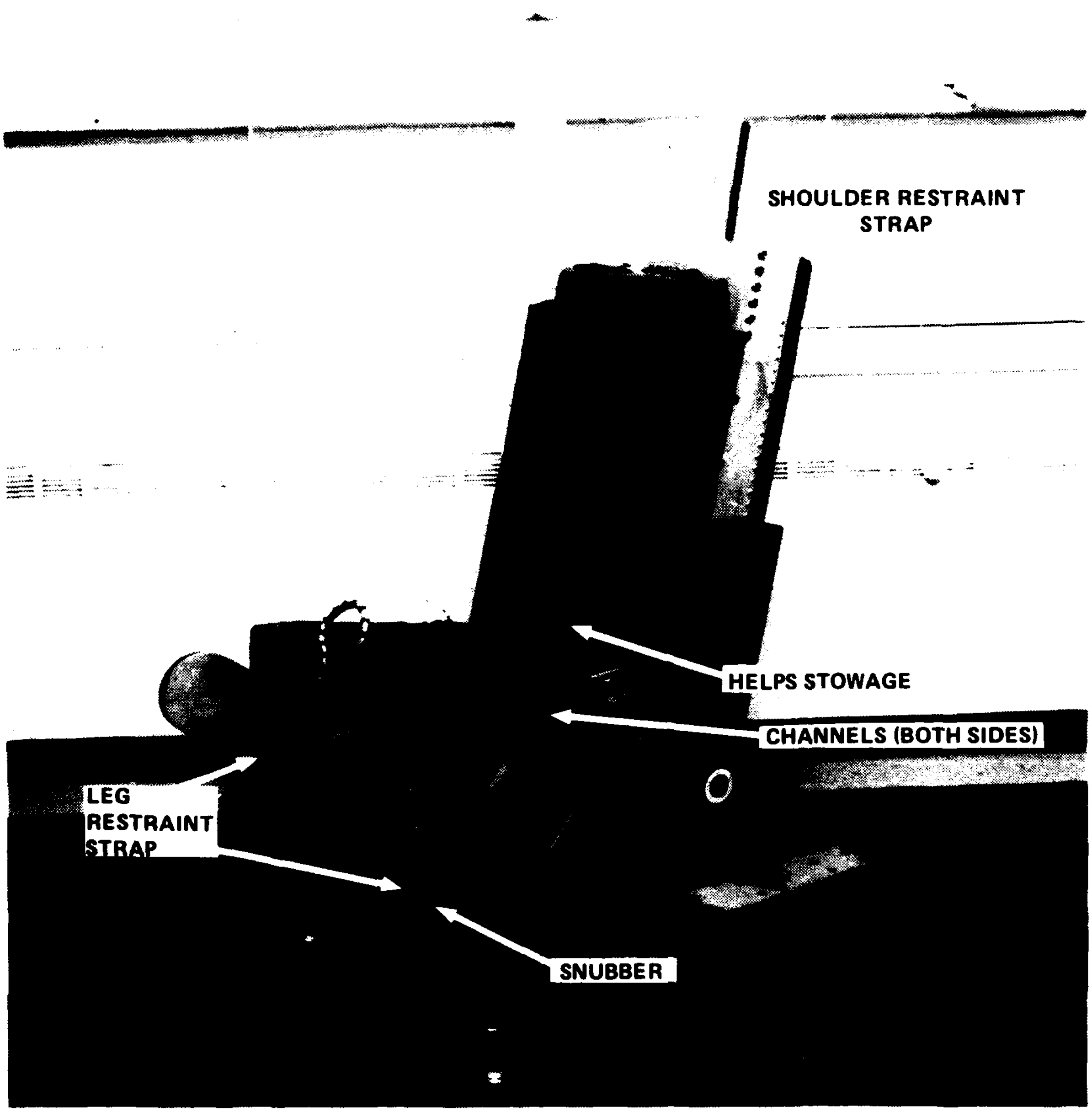

Figure 1. Helps Stowed on MPES Seat

Figure 2. Helps Properly Deployed

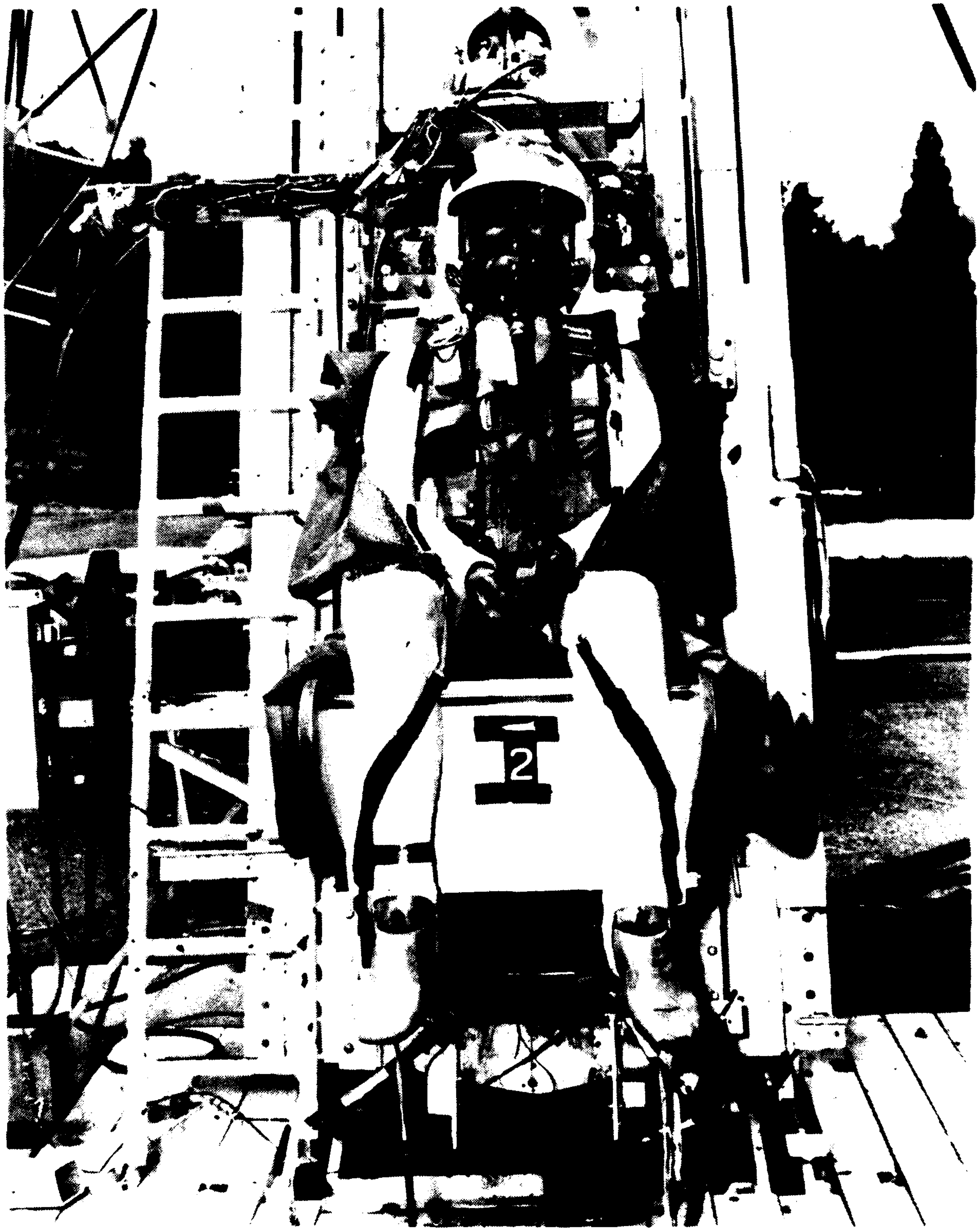

Figure 3. HELPS Cinched-Up

DEPLOYMENT EVALUATION

The majority of the deployments conducted on the HELPS were initiated with the seat on a display stand in an open room. Although not an operational environment, these conditions provided an optimum environment to demonstrate the operation of the system and allowed an unobstructed view for the observers. All deployments were conducted using a 25 cubic inch air bottle with an initial pressure between 1000 and 2000 psi. The HELPS was packed according to procedures previously established except where otherwise noted.

For the deployment process to function properly, the shoulder restraint strap must remain attached to the shoulder deployment bladder during inflation. The bladder positions the shoulder restraint strap above the occupants shoulder before the leg deployment bladder is completely inflated. As the leg deployment bladder inflates, it deploys toward the center of the seat and pulls the shoulder restraint strap from the velcro fastener on the bladder. The shoulder restraint straps position themselves over the occupants shoulders with the arm restraint nets enveloping the elbows.

Two types of deployment failures of the shoulder restraint straps were discovered. In some cases the shoulder restraint straps deployed beside the occupants shoulder, or they remained connected to the deployment bladders following deployment. Most of these deployment failures occurred with subjects having a higher than average sitting height. Although the attachment point of the shoulder restraint strap to the bladder may have been too low, another factor which could contribute to both deployment failures was insufficient inflation pressure in the bladders. An initial supply pressure of at least 1800 psi is required for proper deployment of this configuration. When the shoulder restraint strap did not separate, the leg deployment bladder was held out of its proper deployment position by the strap. Since the strap deployment could be stopped, it could also be slowed down causing the strap to fall short of the top of the shoulder. The higher inflation pressures increased the speed and force of the deployment process, but also increased the likelihood of rupturing a bladder.

An evaluation of HELPS was conducted at the Naval Air Test Center (NATC), Patuxent River, MD. Tests were conducted under static unconfined test conditions and also while confined in an F-14 aircrew station. The results of the NATC evaluation are presented in Reference 2.

The enhancing characteristics of HELPS presented in this report are:

- The passive design of HELPS
- The compatibility of HELPS in the non-deployed state with any size aircrewman and any combination of personal flight equipment.
- The ability of HELPS to effectively restrain the aircrewmans arms and legs if the deployment and cinch-up phases are correctly performed.
- The simplicity of the repack procedures.

The Part I deficiencies of HELPS presented in this report are:

- Failure of HELPS to consistently position the leg restraint lines in the proper location during deployment.
- Failure of HELPS to properly deploy within the confines of the F-14 Crew Station.

DEPLOYMENTS IN AN F-14 COCKPIT

The MPES seat was mounted in an F-14 cockpit at NATC to investigate the effectiveness of the HELPS deployment in an aircraft. Two subjects representing a third and ninety-eight percentile aircrewman were used as seat occupants. Each subject wore flight gear consisting of a flight suit, torso harness, anti-G suit, survival vest, life preserver, helmet, oxygen mask, and a knee board.

The HELPS failed to deploy properly in each test. The leg deployment bladders were the source of failure each time. The bladders snagged on aircraft components at two different points inside the cockpit. These points were the aircraft throttle quadrant and the underneath of the canopy sill. Figure 4 shows a bladder snagged at each location.

The leg deployment bladders inflate by traveling outward and up from their stowage channel. They complete their deployment moving forward and towards the centerline of the seat. Figure 5(a) shows the approximate path of the top of the leg deployment bladder. The outward travel of the leg deployment bladder is the cause of the snagging problem and will likely occur in all aircraft types.

Some unconfined tests were conducted to determine if flat raised seat sides would decrease or prevent the outward travel of the leg deployment bladders. A simulated flat seat side panel did decrease the outward travel of the leg deployment bladder to approximately that shown in figure 5(b). Further testing using wider seat occupants proved that the bladders could be held in the storage channels by the occupants buttocks, thus preventing deployment.

Proper deployment of the leg deployment bladders is necessary to separate and position the shoulder restraint straps and to properly position the leg restraint straps. It has been shown that proper deployment of the leg restraint bladders, as currently configured, can be prevented by the seat occupant or aircraft cockpit components.

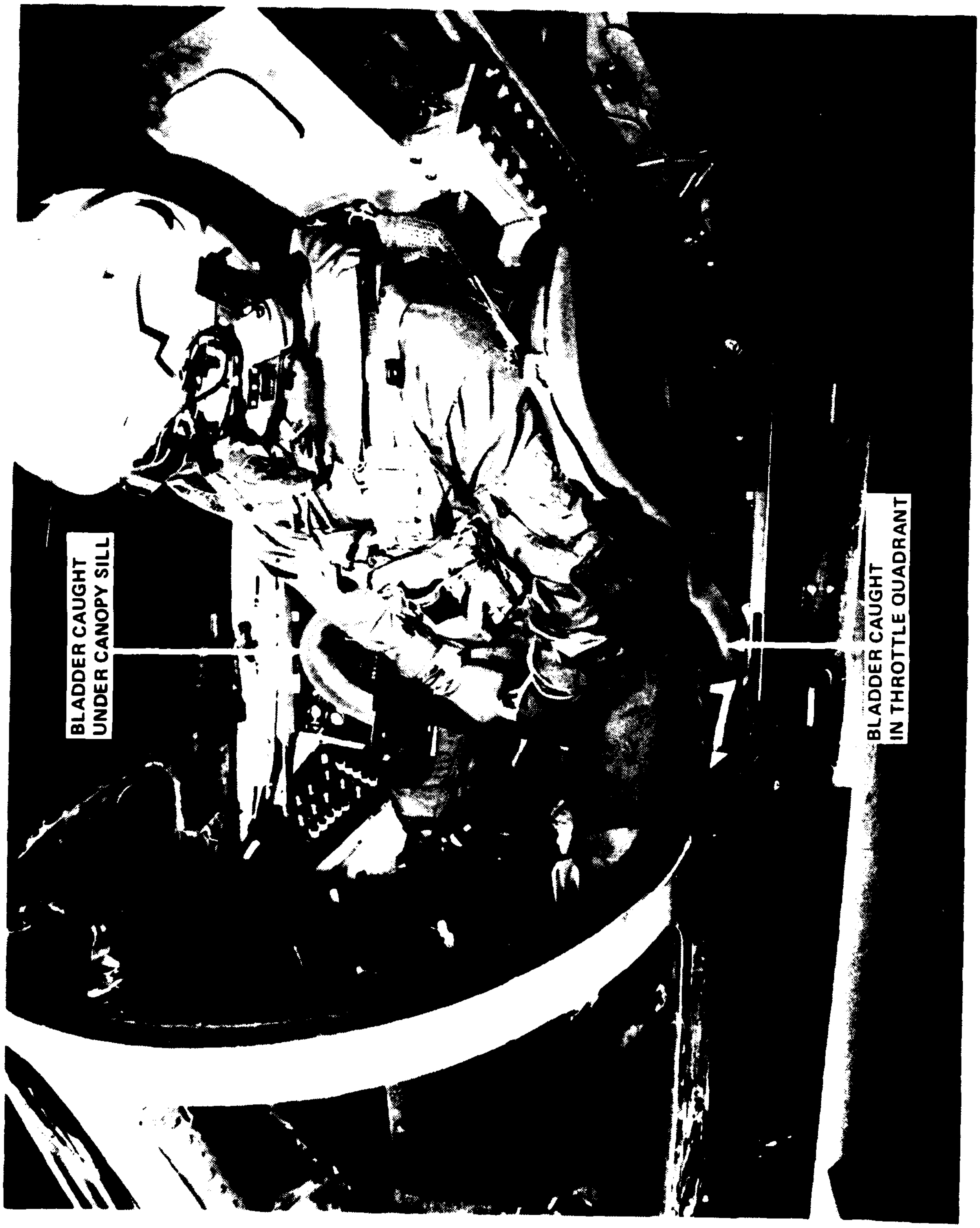

Figure 4. Helps Deployment Inside an F-14 Cockpit

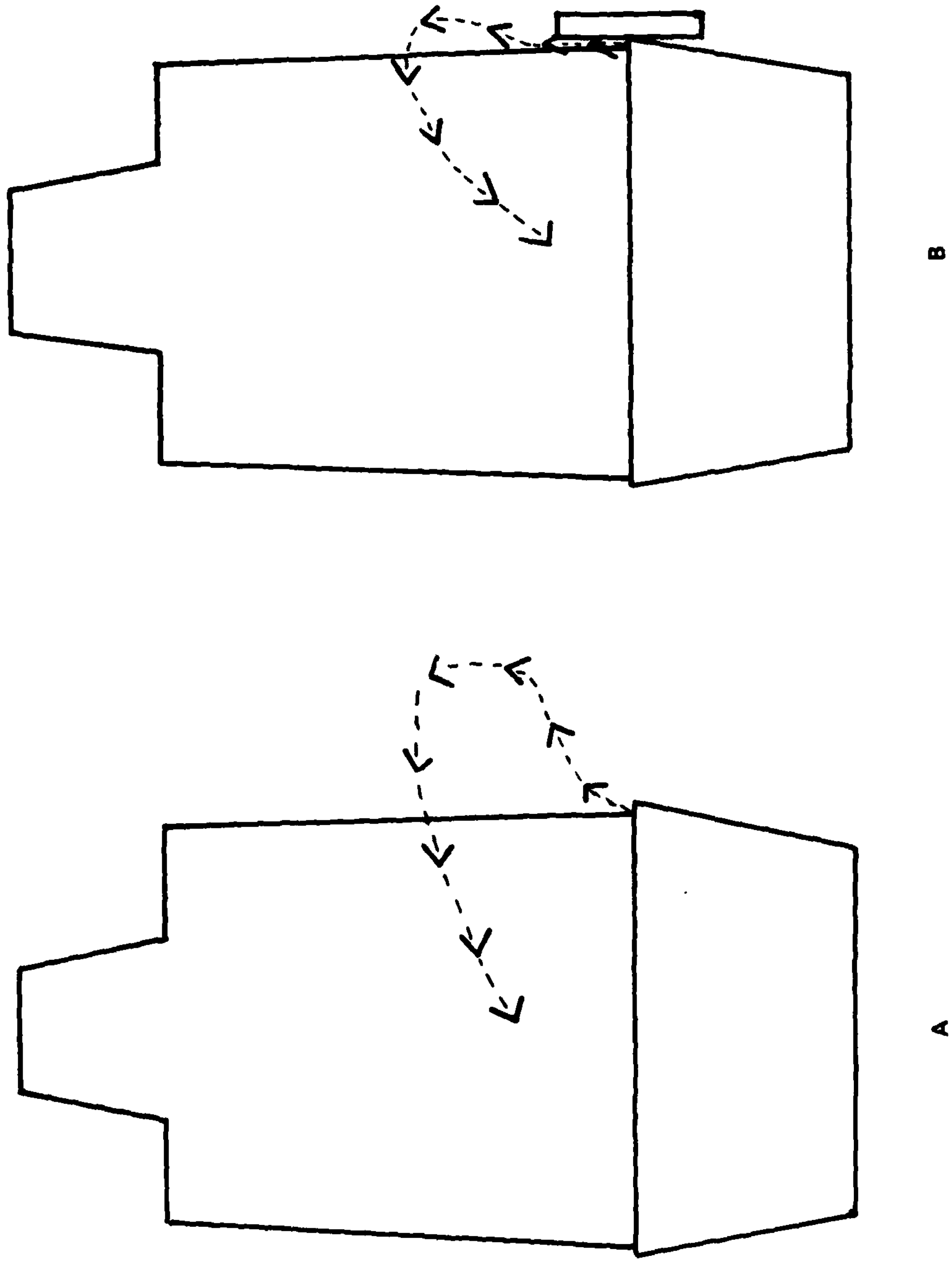

Figure 5. Sketch of Leg Deployment Bladder Travel

WINDBLAST DEPLOYMENTS

Three deployments during a simulated windblast condition were conducted at the Dayton T. Brown, Inc. windblast test facility. A stripped out A-4 cockpit section without a canopy was used to house the MPES seat. An aerodynamic forebody and afterbody were added to simulate as realistic as possible, the wind stream past the cockpit section. Figure 6 shows the test set-up for these evaluations.

Tests 5, 6, and 7 from table I were conducted to evaluate the HELPS deployment. In test 5 the HELPS was initiated before exposure to the windblast to represent some deployment time in still air as would be the case when the seat ejects through the canopy. In tests 6 and 7 the HELPS was initiated simultaneously with the windblast to simulate HELPS deployment concurrent with canopy removal. It is realized that the windstream conditions used for testing the HELPS will not match an actual aircraft ejection windstream, but the failure of HELPS to properly deploy under simulated dynamic conditions indicates that the current HELPS deployment concept will not function satisfactorily in an actual ejection environment.

Figures 7 and 8 show the HELPS system before and after test no. 5. Although the HELPS components are in proper position after the test, proper deployment didn't occur. Film analysis showed the bladders hung-up during the still air time between HELPS initiation and airblast initiation. The airblast actually freed the bladders and allowed them to properly deploy.

The remaining deployment tests were conducted with the HELPS initiated simultaneously with the windblast. The HELPS failed to deploy properly in these tests. Figure 9 shows four different sources of deployment failure. The wind force was greater than the forward acting force of the shoulder deployment bladders. Therefore, the bladders could not position the restraint straps above the occupants shoulders. The leg deployment bladders snagged under either the canopy sill or the dummy's arm. Before each windblast test, the dummy's hands were positioned near the location of a lower ejection handle. The windblast forced the dummy's arms back and up from this location, so the leg deployment bladder deployed underneath the dummy's arm. The inability of the shoulder bladders to properly deploy could affect the deployment of the leg bladders since they are connected by the kevlar straps.

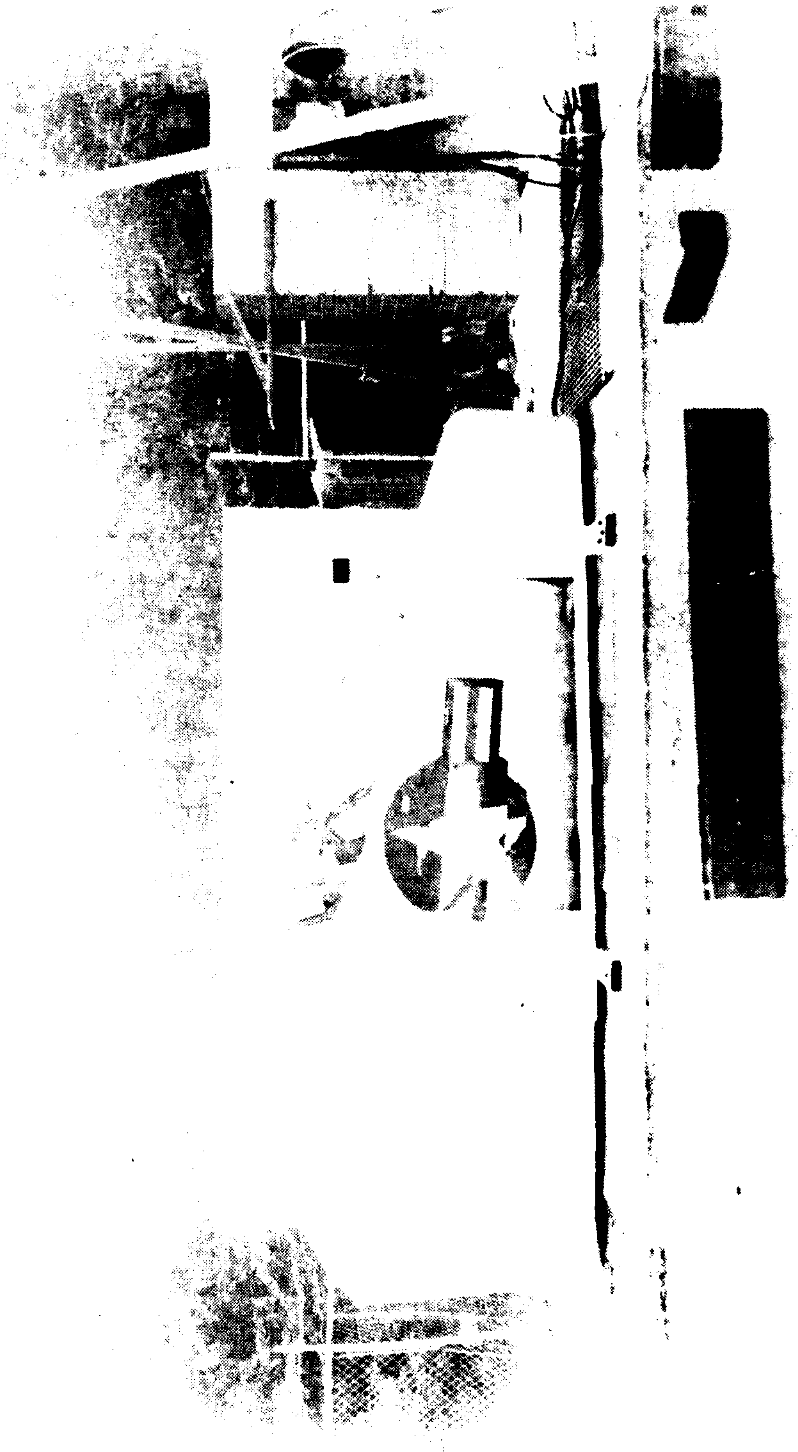

Figure 6. Cockpit Section for Windblast Testing

TABLE I.

HELPS

COCKPIT WINDBLAST EVALUATION

Test No.	Date	HELPS Function Tested	Airspeed (Knots)	Deployment Time (Sec.)	Seat Ht. (in.)	Result
1	5-28-82	Cinch-up	600	Predeployed	0	Success
2	6-1-82	Cinch-up	600	Predeployed	9	Failure
3	6-1-82	Cinch-up	450	Predeployed	9	Failure
4	6-1-82	Cinch-up	450	Predeployed	18	Success
5	6-2-82	Deployment	600	To - .250	0	Failure
6	6-3-82	Deployment	600	To	0	Failure
7	6-4-82	Deployment	450	To	0	Failure

Figure 7. Pretest View for Deployment During Windblast

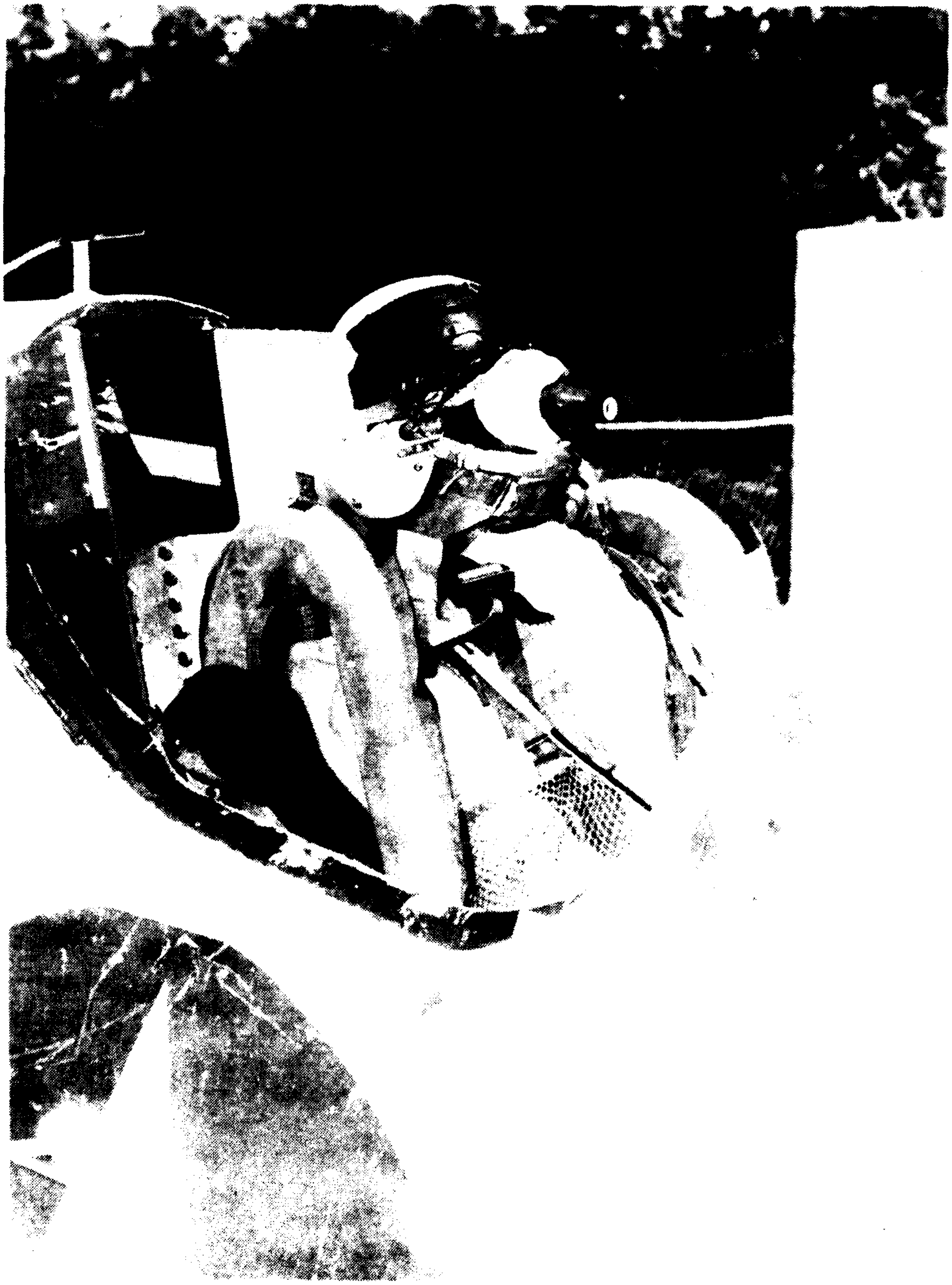

Figure 8. Post Test View for Deployment During Windblast

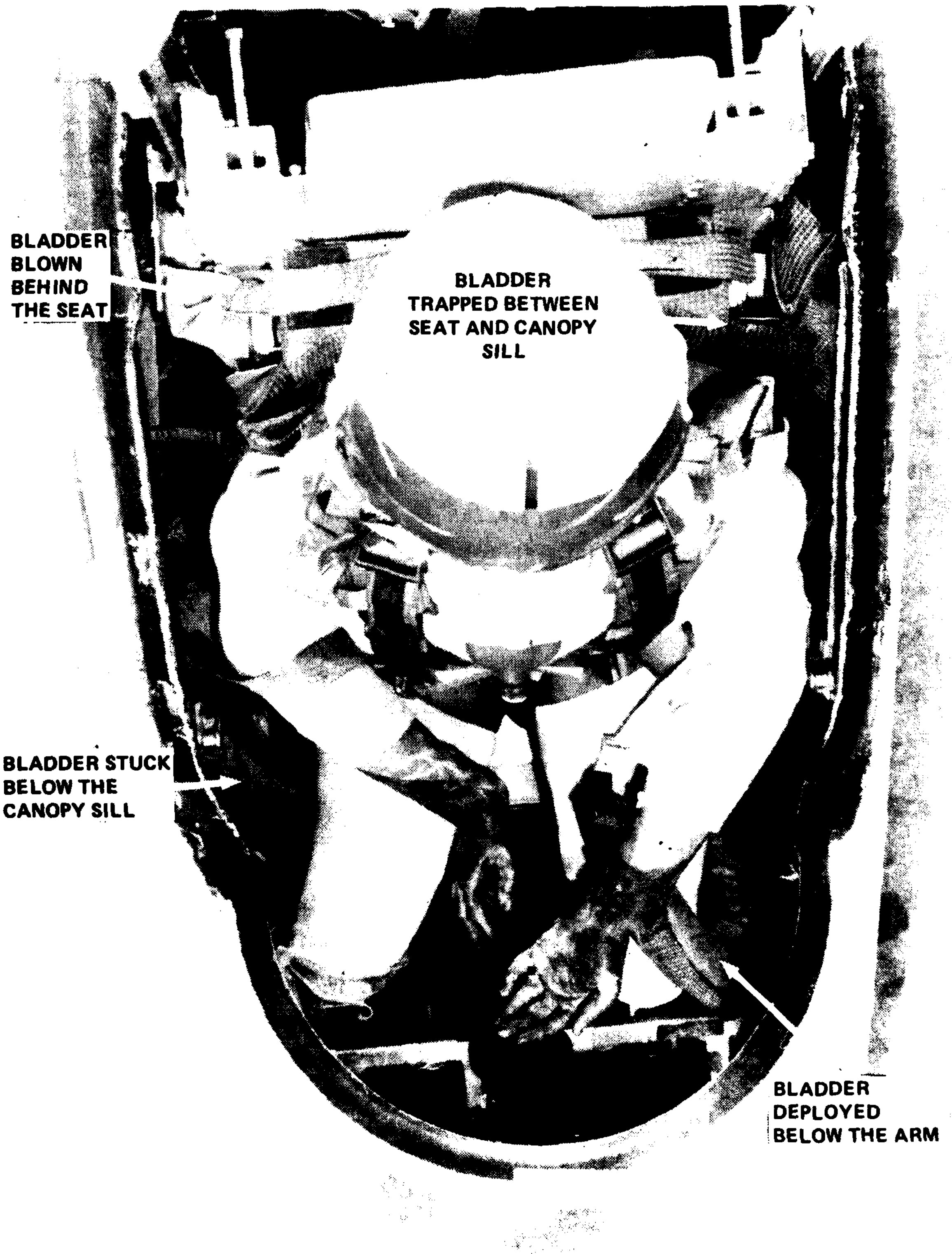

Figure 9. Post Test 6 View for Deployment During Windblast

The current bladder deployment configuration of the HELPS is unreliable and therefore unacceptable. A redesign of this concept may provide acceptable results. Stronger bladders, higher inflation pressures, reshaped bladders, and relocated bladders could significantly improve the operating characteristics and provide the passive feature desired. Careful design on an aircraft to aircraft basis would be required to assure that cockpit components would not interfere with system deployment.

CINCH-UP EVALUATION

Following deployment, the HELPS must tighten or cinch-up over the occupant to provide the necessary restraint. The cinch-up occurs as the seat travels up the ejection rails. A tensioning strap is attached between the HELPS leg restraint line and the cockpit floor. Seat travel pulls the restraint straps tightly over the occupant through the tensioning straps. Rip stitch webbing in line with the tensioning straps begins to tear at a pre-set load of 400 pounds to apply the proper restraint force and to allow the seat to separate from the aircraft.

The cinch-up phase was investigated on the NADC ejection tower and the Dayton T. Brown windblast test facility. Dummies of various sizes were used during these evaluations. An additional cinch-up evaluation with human subjects to determine the physiological acceptability of the cinch-up operation may be required at a future time.

EJECTION TOWER EVALUATION

The ejection tower evaluation was conducted to demonstrate the ability of the HELPS to both deploy and entrap the occupants limbs during the cinch-up phase. Eight ejection tower tests were conducted in July of 1981, using both five and ninety five percentile dummies. Data from these tests are shown in table II. Typical seat displacement-vs-time curves and cinch-up pull force-vs-time curves are shown in figures 10 and 11 respectively.

To obtain the delay times listed in table II, two firing lanyards were used. In the first five tests, both lanyards were pulled simultaneously with slack in the catapult firing lanyard to initiate HELPS first. The air supply bottle was relocated off the seat to be initiated by the catapult firing lanyard. The relocation required additional tubing and a one way valve between the air supply bottle and the bladders. Before the final three tests,

TABLE II

HELPS DEPLOYMENT AND CINCH-UP EVALUATION

Test No.	Date	Dummy Occupant Percentile	Ejection Delay From Bladder Inflation (Sec.)	Seat Acceleration (G)	Test Item Response Arm Restraint Left	Test Item Response Arm Restraint Right	Test Item Response Leg Restraint Left	Test Item Response Leg Restraint Right
1	7-15-81	5	.07	11.7	OK	OK	OK	F3
2	7-15-81	5	.10	14.0	OK	OK	OK	OK
3	7-17-81	95	.08	12.6	F2	F1	OK	F3
4	7-17-81	95	.09	12.9	OK	F1	OK	F3
5	7-23-81	95	.10	10.2	F2	F1	OK	F3
6	7-23-81	95	1.31	12.6	OK	OK	OK	OK
7	7-24-81	95	1.60	12.6	OK	OK	OK	F3
8	7-24-81	95	1.38	12.0	OK	OK	F3	OK

F1 Strap wasn't separated by the knee bladder

F2 Strap missed shoulder

F3 Strap missed knee

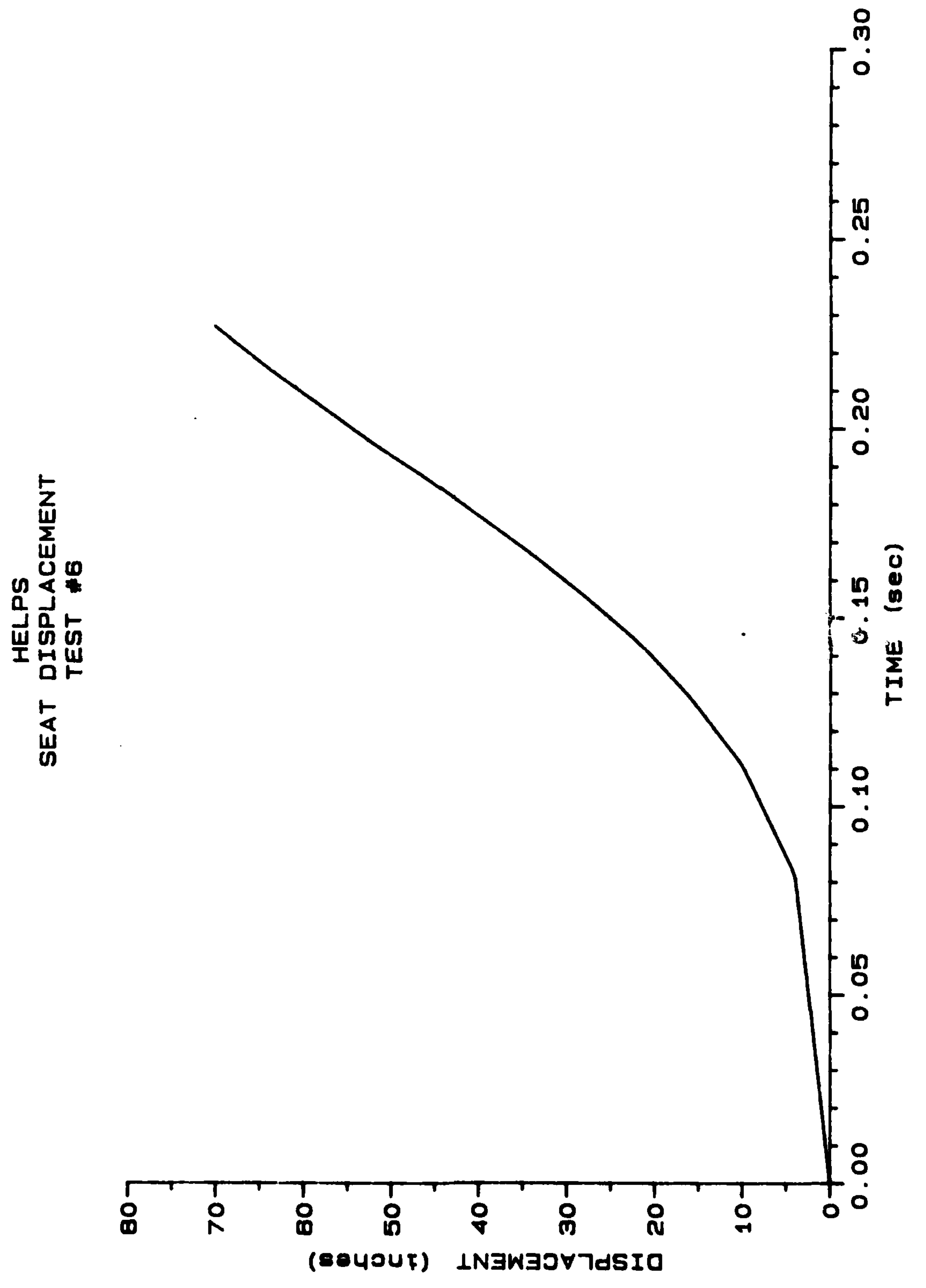

Figure 10. Seat Displacement vs Time

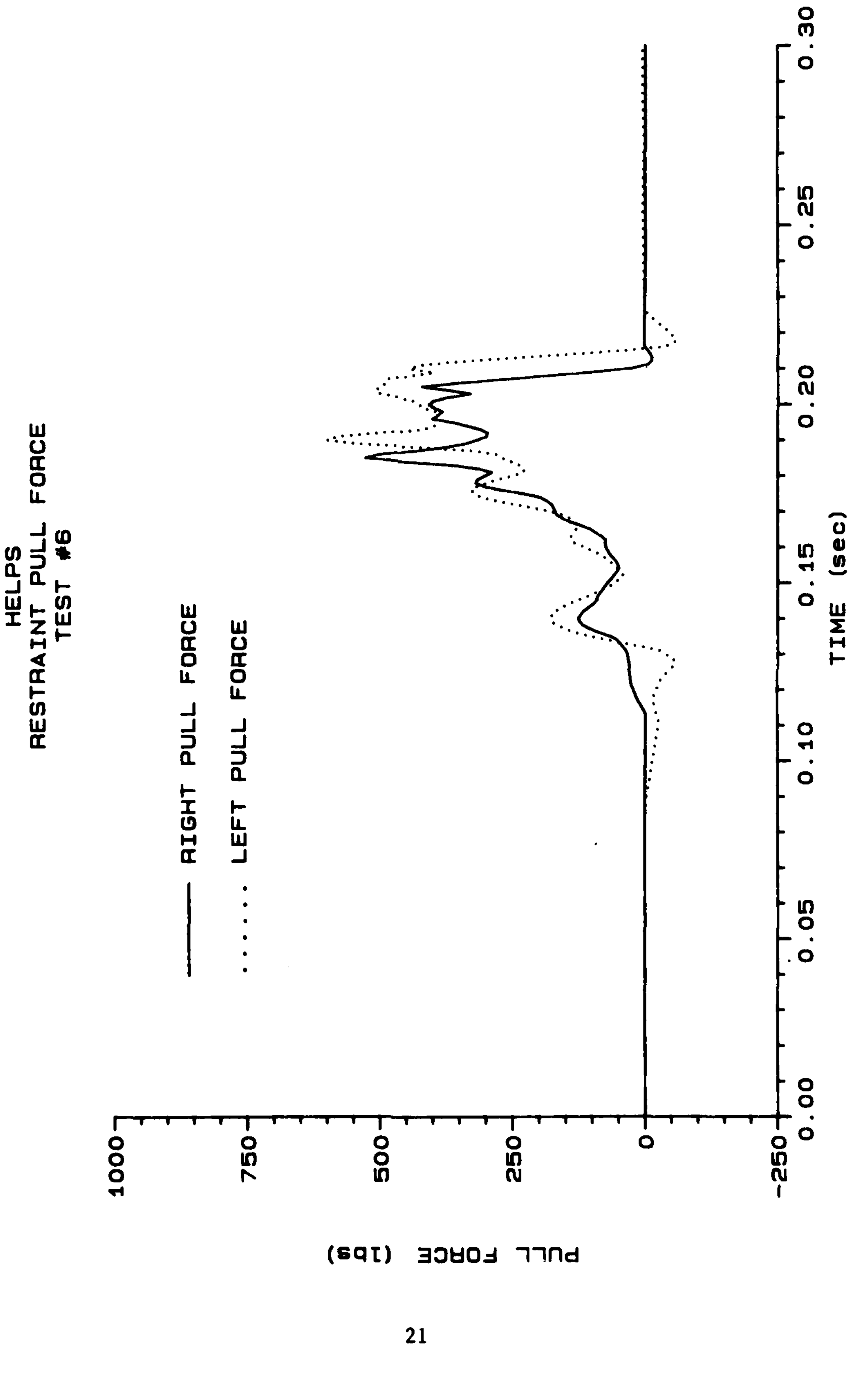

Figure 11. Clinch-Up Pull Force vs Time

the air supply bottle was moved back onto the seat and initiated by a separate lanyard. This change was necessary because the extra distance in the inflation line resulted in slower deployment times.

Views of a successful cinch-up are shown in figures 12 and 13. Cinch-up failures occurred because of the following two problems:

1. The shoulder restraint line did not tighten over the occupants shoulder, (figures 14 and 15). Although it would appear that the HELPS, if cinched in this manner, would restrain the arms, they actually would be more susceptible to dislodgement during an unstable ejection.

2. The leg restraint lines did not capture the legs, (figures 14 and 16). Three reasons for the failure to capture the legs were evident. These were:

- The bladders were not deployed to their proper position.
- The velcro connection of the leg restraint strap to the bladder prematurely disconnected during the deployment.
- The bladders twisted from their properly deployed position as the leg restraint straps separated from the velcro.

A problem with the snubbing system was also discovered during the tower evaluation. The shrink tubing jammed in the snubber blocks, as shown in figure 17. This jamming could cause the rip stitching to begin tearing before the system is completely tightened. It could also allow the kevlar line to slip back through the shrink tubing because the tubing kept the snubber pawl jammed in the unlocked position. The shrink tubing had to be removed to continue the testing.

WINDBLAST CINCH-UP EVALUATION

The cinch-up phase of the HELPS operation was also investigated during a windblast environment. These tests were conducted at Dayton T. Brown, Inc. under the same contract as the windblast deployment tests discussed previously. This cinch-up evaluation was conducted with the HELPS system predeployed and properly positioned over the dummy's body. The seat was raised to the proper test heights, of, 0, 9, and 18 inches above the cockpit floor. With the air in the bladders, the tensioning straps were pulled to the cockpit floor so the restraint straps would be positioned properly for that amount of seat travel. Twenty-five to thirty psi of air was maintained in the bladders during the windblasts.

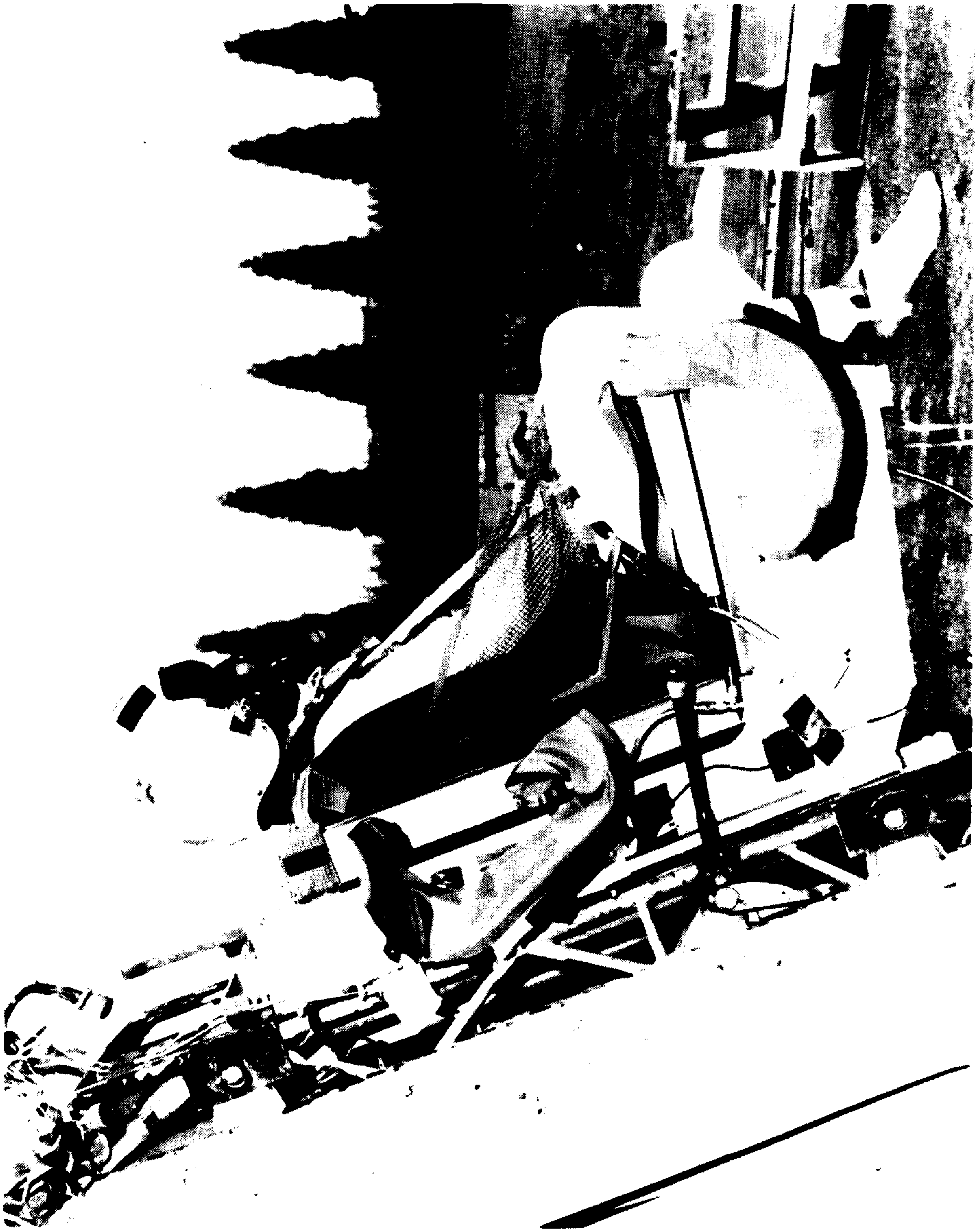

Figure 12. Side View HELPS Properly Cinched

Figure 13. Front View of HELPS Properly Cinched

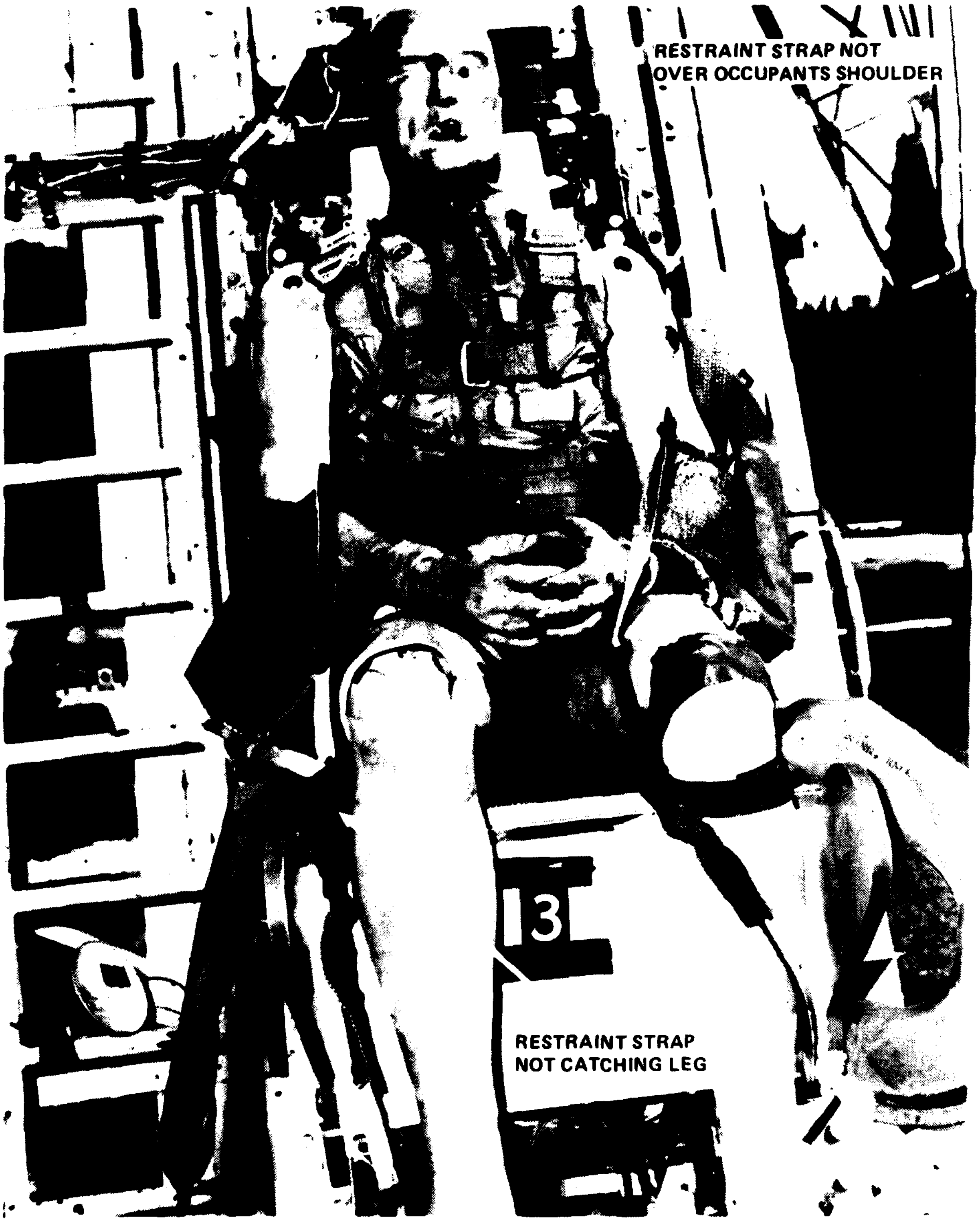

Figure 14. Improper Restraint

Figure 15. Close-Up of Improper Shoulder Restraint

Figure 16. Close-Up of Improper Leg Restraint

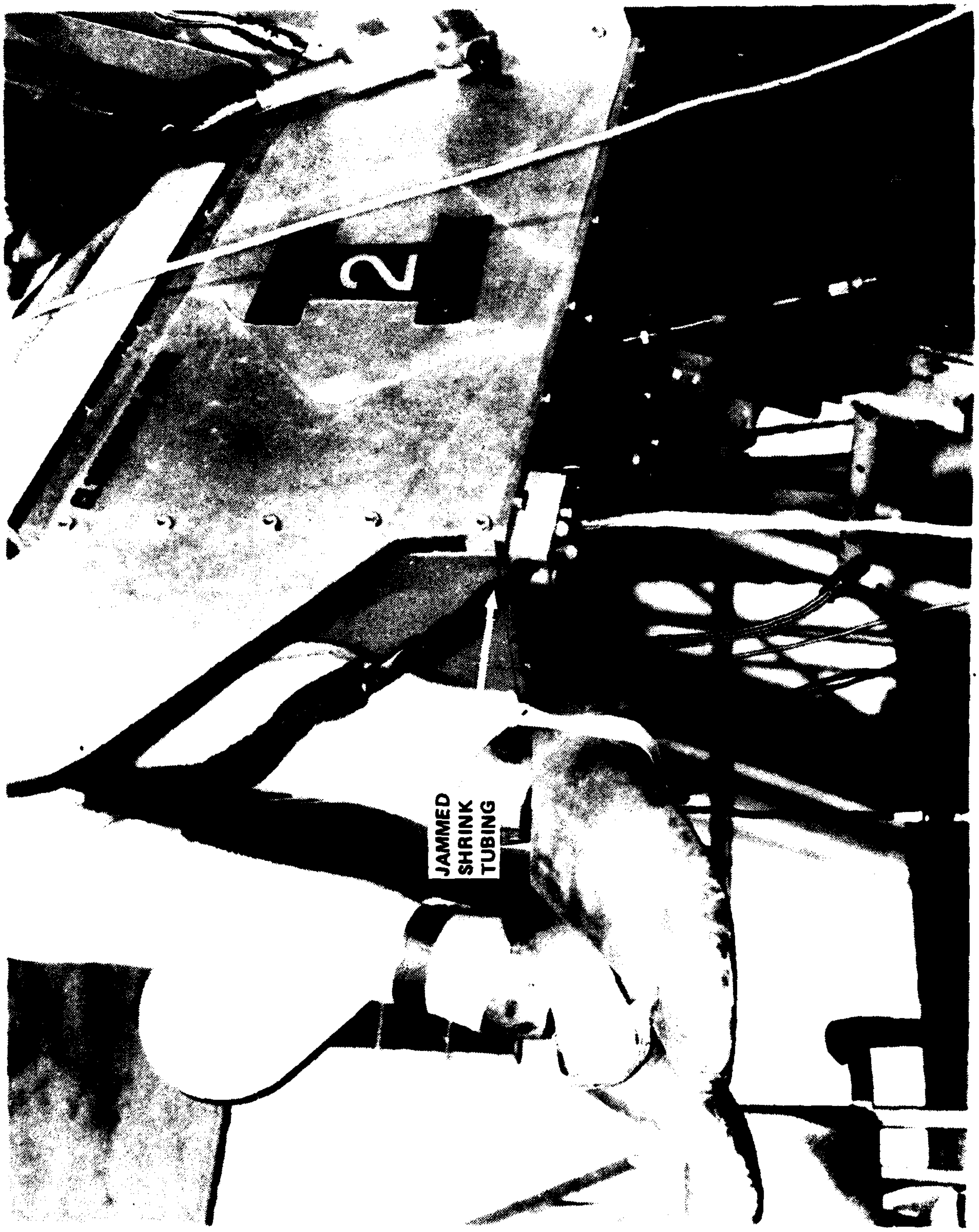

Figure 17. Snubber Block with Jammed Shrink Tubing

Tests 1 thru 4 in table I summarizes the test conditions for the cinch-up evaluation. With the seat full down, the windscreen protected the dummy enough that the HELPS stayed in position over the dummy. With the seat raised eighteen inches, the HELPS was tensioned sufficiently so that it also remained in position over the dummy during the windblast. At nine inches of seat travel, the HELPS was blown off the dummy's shoulder, as shown in figures 18 and 19. This test was considered unsuccessful since the arm restraint straps did not remain in position across the dummy's shoulders as required.

The cinch-up phase of HELPS appears to be easily correctable to an acceptable configuration if the deployment problems can be corrected. When the bladders properly positioned the restraint straps, successful cinch-ups occurred. Stronger bladders would decrease the twisting motion that occurred during cinch-ups. A faster acting tensioning line can be easily developed to assure that the system is tightened over the occupant before entering the windstream. Also, a new snubber mechanism will be required to assure that no binding or jamming occurs during the cinch-up phase.

WINDBLAST RESTRAINT EVALUATION

A windblast test program was conducted at Dayton T. Brown, Inc. under Contract No. N62269-80-G-0212, Task Order 0008, to determine the HELPS effectiveness in restraining the limbs. A ninety-fifth percentile anthropomorphic dummy dressed in a flight suit, MA-2 integrated torso harness, boots and helmet was used as the test subject. The dummy's joints were loosened to decrease the frictional resistance to allow as much limb motion as possible with no restrictions except for the restraint. The restraint system was preset over the dummy in the proper deployed and cinched condition as it would be when it leaves the aircraft cockpit. Both restraint straps were tensioned to the 400 lb design limit and retained by the snubbers. Tests were conducted with the seat and dummy at various pitch and yaw attitudes and fully exposed to a windblast between 400 and 700 knots. A summary of the test conditions is contained in table III.

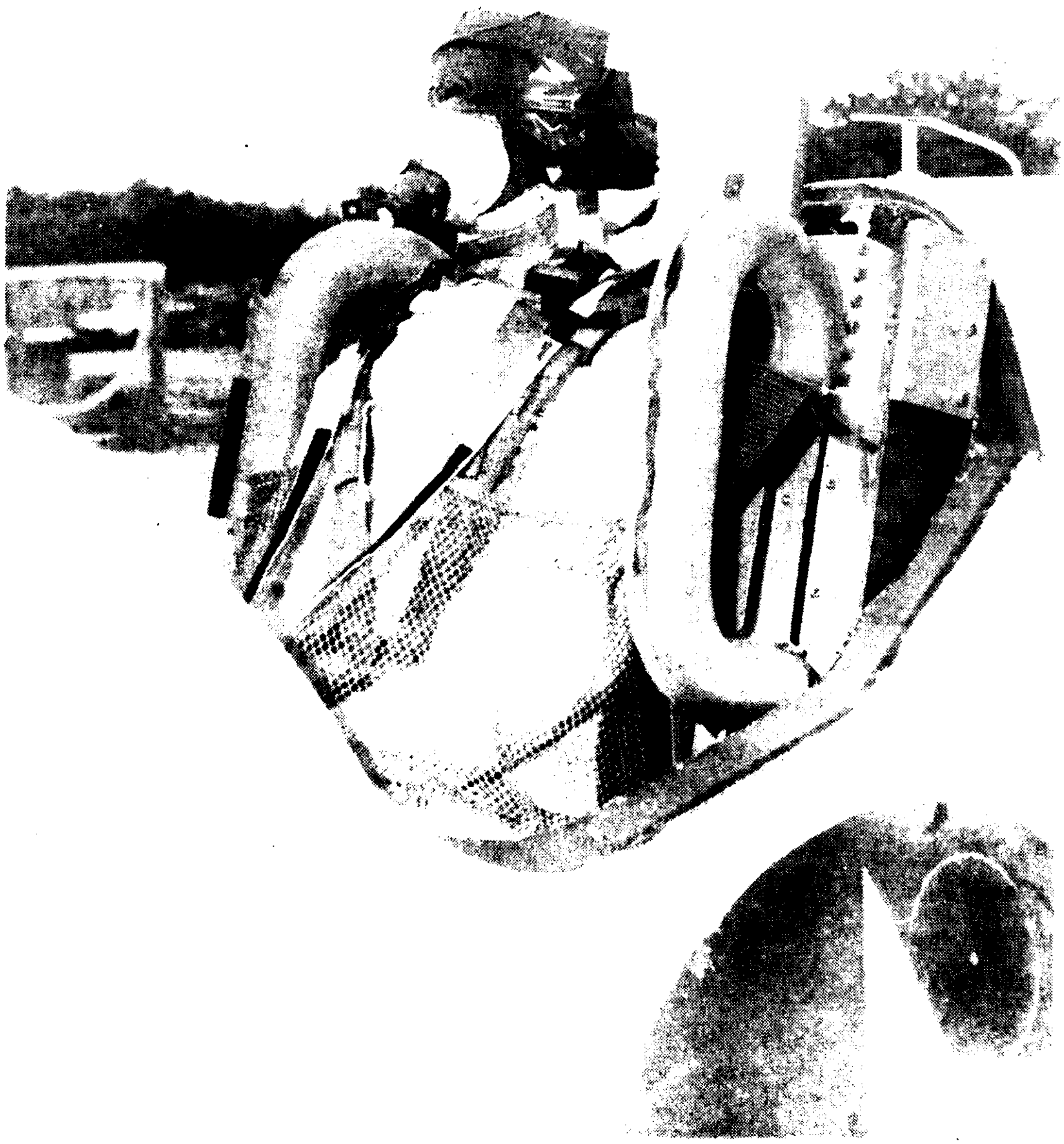

Figure 18. HELPS Before Windblast

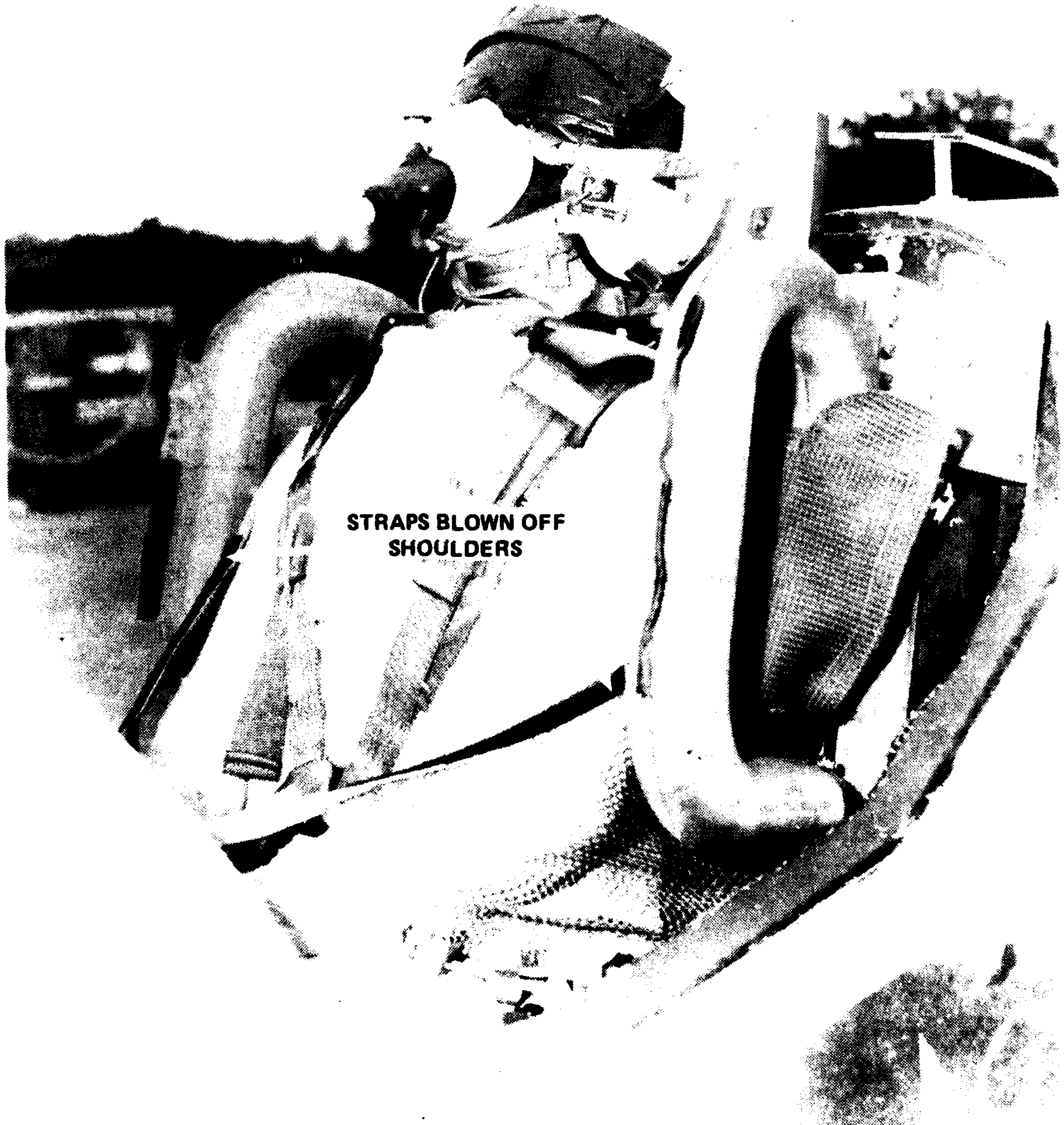

Figure 19. Helps After Windblast Test 3

TABLE III

HELPS WINDBLAST RESTRAINT

TEST CONDITIONS

Test No.	Date	Airspeed (knots)	Seat Attitude 1/
1	4-16-82	439	13^{o} Aft Pitch, 0 YAW
3	4-16-81	435	13^{o} Aft Pitch, 45^{o} Starboard YAW
3 2/	4-21-81	690	13^{o} Aft Pitch, 0 YAW
4	4-22-81	706	58^{o} Aft Pitch, 0 YAW
5	4-23-81	630	13^{o} Aft Pitch, 45^{o} Port YAW
6	10-19-81	615	13^{o} Aft Pitch, 0 YAW
7	10-20-81	3/	13^{o} Aft Pitch, 90^{o} Port YAW
8	10-20-81	588	13^{o} Aft Pitch, 90^{o} Port YAW
9	10-21-81	4/	32^{o} Forward Pitch, 0 YAW

1/ 0 Pitch is the seat back straight up, 0 YAW is the seat facing the windblast.

2/ This was considered a no test because the windblast duration was less than planned.

3/ The velocity was not recorded due to instrumentation failure (set for 600).

4/ The velocity was not recorded due to test article interference of the Pitot tubes (set for 600).

Although some undesireable limb motion occurred, the HELPS prevented the dummy's arms and legs from flailing. Considerable arm motion occurred beneath the arm restraint straps and arm restraint netting, but the arms never dislodged from the restraint. The most extreme arm motion is depicted in figures 20 thru 23 which are pre and post test photos of tests 4 and 6. Two factors contributing to this arm motion are a poor connection of the arm restraint straps to the inertia reel straps, and weak stitching holding the arm restraint netting to the seat sides and the arm restraint straps. These factors allowed the HELPS to loosen as load was being applied by the arms. Downward lateral leg displacement occurred in test 8, but the legs always remained against the front of the seat bucket. Figures 24 and 25 show this motion. This motion occurred because the strap snubber was not able to restrain the legs against the applied windblast load. As the strap pulled back through the snubber, slack was introduced throughout the system.

Although the arms and legs were not dislodged, the degree of protection provided was considered marginal. In the event of an unstable ejection where the seat is experiencing pitch and yaw rates, there is a probability that the limbs wou'd not be contained and flail injury would occur.

A failure of the HELPS seat attachments occurred in test 5. The left side channel was pulled from the seat back. Figures 26 and 27 show the test dummy almost blown completely off the side of the seat. A contributing factor to this failure is the poor lateral restraint provided by the MPES seat. The HELPS was being required to hold the dummy on the seat, instead of just restraining its arms. This same seat and HELPS were repaired with strengthened side channel attachments and used in all 9 tests.

The stitching that holds the arm netting to the restraint webbing or seat side channel also failed as indicated in figure 23. The netting was resewn with stronger thread and the system was reused.

The HELPS restraint configuration once deployed and properly cinched was found to provide satisfactory restraint for both the arms and legs up to the limits tested. It is also possible to improve the configuration so that the restraint will be tighter and also minimize limb motion under the restraint.

Recommended changes would be to provide a firmer anchor for the top of the shoulder restraint straps, a change in the length of the restraint strap, stronger seat connections, improved stitching requirements, and an improved strap snubber to maintain a tight restraint over the occupant.

Figure 20. View of HELPS Before Aft Pitch Windblast

Figure 21. View of HELPS After Aft Pitch Windblast

Figure 22. View of HELPS Before Head On Windblast

Figure 23. Post Test View of Test 6

Figure 24. View of HELPS Before Way Windlblast

Figure 25. View of HELPS After Yaw Windblast

Figure 26. View of HELPS After Attachment Failure

Figure 27. HELPS Attachment Failure

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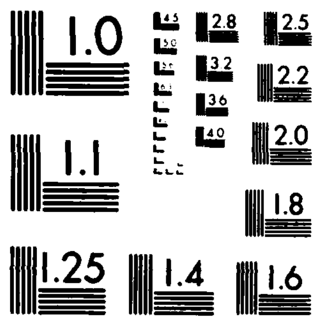

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Kenneth Miller
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974

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The HELPS performance evaluation consisted of a series of tests to evaluate deployment, cinch-up, and restraint effectiveness. Test facilities used to evaluate HELPS included the NADC Ejection Tower, the Dayton T. Brown Windblast Facility and an F-14 Aircraft which was made available at the Naval Air Test Center, Patuxent River. The following pages describe the results of these evaluations.

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